METHODS OF DRIFT CONTROL

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ABSTRACT

Factors effecting the amount of spray drift include: spray droplet size, droplet release height, wind velocity and direction, air temperature and relative humidity, atmospheric stability, and droplet release velocity. These factors are important to several application methods, i.e., aerial, ground boom, and air-blast tree sprayers. Downwind deposits from spray drift can be minimized by optimizing these factors, i.e., spraying a low percentage of driftable droplets (< 150 μm), releasing droplets close to the target, spraying in cool humid conditions, with low wind velocities. Of course, if integrated pest management techniques are applied, wherein spray is applied only when required, then less spray will be applied and drift will be automatically reduced. Other special techniques can be used for each application methods. This review contains some examples of drift measurements using boom and air-blast sprayers, and lists management practices for minimizing drift for each application method. For ground boom sprayers, drift management practices include: air-assisted sprayers, electro-static sprayers, using nozzles designed to produce larger droplets and to produce fewer small droplets, such as air-induction, or dual orifice nozzles, applying larger volumes of water, which will require larger nozzles, and using mechanical shields to reduce the effect of wind on the spray cloud. For orchard spraying, one drift reduction technique is to use special spray treatments on the last few downwind rows. These treatments may include spraying only into the wind, using special nozzles that produce large droplets, timing spray applications so the wind direction is favorable, or even using pest control agents with low toxicity for this part of the orchard. Other drift reduction techniques include: use special equipment, such as tunnel sprayers; using hedgerows to filter out spray droplets from the air; and matching the sprayer air jet velocity and volume to the tree being sprayed, and applying the proper spray volume for the tree canopy being sprayed.

INTRODUCTION

Spray drift is defined as the movement of spray out of the intended sprayed area. Some ways pesticides move include: 1) spray droplets can be transported out of the sprayed area by the wind, 2) volatilization of pesticide formulation after application, 3) movement of small specks of pesticide that is lifted from leaf surfaces or the ground after it dries, 4) pesticide deposited on the ground may be transported

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by water or soil particles into the water table or into drainage ditches, streams or ponds. In this study we will only consider the movement of spray droplets during or immediately after spraying as drift. Other means of pesticide movement are difficult to control by changing the spraying equipment or operating procedures.

Factors effecting the amount of drift include: spray droplet size, small droplets are more easily transported by wind currents; droplet release height, droplets released at greater heights take longer to reach the ground and can be carried further; wind velocity and direction, higher velocity means the droplets will be transported greater distances during the time they take to fall to the ground; air temperature and relative humidity (water vapor deficit) affect the evaporation rate of droplets and thus the drift potential; atmospheric stability may affect the vertical transport of the spray cloud, and, in this way, the droplet dispersion pattern; and droplet release velocity may affect droplet travel time from release to impaction on the ground.

AMOUNT OF SPRAY DRIFT

The amount of spray drift is related to the field size and shape, and type of spray application. Many studies have collected spray across the sprayed swath or on the target tree canopy. We will report a sample of these results, as drift is related to the amount of spray that is not deposited in the intended swath.

Ground sprayers

Bode et al. (1976) reported on a series of experiments using the dual-tracer technique to compare two boom sprayer systems with each pass. They measured climatic factors and used a range of concentrations of Nalco-Trol, nozzle type, pressure, and height, and liquid application rates. They measured ground deposits in the swath and from 0.5 to 312 m downwind. A portion of their results are shown in Table 1. Adding Nalco-Trol to the spray mix consistently reduced total spray loss and reduced downwind deposits even more. Increasing the concentration of Nalco-Trol in the mix decreased spray drift deposits for the concentrations used in this study. Low pressure nozzles (8002LP) reduced drift in 4 of 5 trials; TK-2 flooding, flat-fan nozzles decreased drift in 3 of 4 trials but usually not as much as LP nozzles. The Raindrop nozzle decreased downwind spray recovery in 5 of 5 trials compared to an 8002 nozzle, overall drift from the raindrop nozzle was similar to drift from the low pressure nozzle. Wind and other climatic factors varied among experiments so comparisons not paired on the same spray trial must be made with caution.

Goering and Butler (1975) measured downwind ground deposits for a boom sprayer equipped with two booms so that paired trials could be made. They concluded that Nalco-Trol reduced drift deposits by 49 to 75 percent; lowering nozzle height and nozzle pressure decreased drift. Increased air turbulence (Richardson No.) produced greater spray loss but less downwind deposits and increased horizontal wind speed produced greater spray loss but produced either greater or smaller drift deposits, depending on other meteorological factors.

Table 1. Drift from boom sprayer, ground deposits. Adapted from Bode et al. (1976)

Nozzle type, pressure, kPa	Tank mix	Total spray recovered, %	Spray drift, % (of recovered)	Drift beyond 2.5 m, % (of recovered)	Drift beyond 2.5 m, if 400 m sprayed, %
Flat-fan 8002, 170 to 345	Water	73 to 87	5.2 to 20.8	1.1 to 3.7	2.2 to 7.1
8002, 170 to 345	Water + Nalco-Trol (0.03 to 0.125%)	68 to 97	1.4 to 12.3	0 to 1.8	0 to 2.26
8002LP,100	Water	77 to 101	0.3 to 9.1	0.03 to 1.2	0.03 to 2.0
Flooding TK-2, 69	Water	59 to 107	1.8 to 6.5	0.1 to 0.4	0.1 to 0.5
Raindrop, 276	Water	91 to 103	2.7 to 6.7	0.2 to 0.7	0.2 to 1.1

Table 2 presents results of an exercise designed (Maybank et al., 1978) to calculate the total airborne spray that might leave the downwind edge from spraying a section (260 ha) of land. They calculated these amounts by overlapping measured airborne spray downwind for one spray swath. If all airborne spray left the field within 4 m of the ground, then total airborne drift through this region would be from 95 to 580 mg/m^2 (depending on application type and conditions) if 55 mg/m^2 were applied. Of course, airborne spray will likely be transported to much greater heights than 4 m by the time it travels 1.7 km, but this exercise does point out how much airborne spray may leave the edge of a sprayed field.

Table 2. Estimates of mass flux from spraying of a section of land (1.7 by 1.7 km) at a rate of 55 mg/m^2. Adapted from Maybank et al. (1978).

Relative contribution to drift from	Downwind field edge			500 m further downwind		
	Aircraft lapse	Ground rig lapse	Ground rig inversion	Aircraft lapse	Ground rig lapse	Ground rig inversion
first swath	1.0	1.0	1.0	0.1	0.2	0.3
2nd –5th swaths	1.3	2.0	2.4	0.3	0.7	1.1
6th-10th swaths	0.9	1.7	2.2	0.4	0.9	1.3

11th-30th swaths	2.1	5.0	6.8	2.3	3.4	5.1
31st-120th swaths	4.4	14.7	25.4	3.54	12.5	22.3
Total	9.7	24.4	37.8	5.5	17.7	30.1
If initial drift is:	30%	3%	3%			
Ave initial drift density(1 swath) to 4 m height (mg/m^2)	60	5.4	5.4			
Total drift (all swaths) ave to 4 m height (mg/m^2)	580	130	200	330	95	160
Ave to 9 m height (mg/m^2)	230	50	80	130	35	65

Air-blast sprayers

Spray accountability

A question we may ask ourselves is: can we account for all of the spray applied to orchards? What portion is deposited on the canopy, on the ground and remains airborne beyond a certain distance downwind? Most of the results presented here were for full-foliage trees, so we will consider the case of air-blast spraying of trees with foliage. We calculated percentages on the basis of tracer applied per unit area. Thus the results are worst case values. If more than the outside row were sprayed, some of the downwind spray would deposit within the sprayed area and a lower percentage of the total spray would be deposited downwind from the orchard. Measured deposit on foliage by Herrington et al. (1991) were about 40% for air-blast sprayers. Siegfried and Holliger (1996) stated that about 40-50% of spray was deposited on the leaves and fruit, about 20% on the ground and about 20% lost as drift. The total spray deposited on the ground from the orchard edge to 30 m downwind was calculated and shown in Fig. 1 for several of studies by Fox et al. (1990, 1993a,b, 1994) and Ganzelmeier (1995). The mean total ground deposit was about 10 to 15% of applied spray. Airborne spray deposits

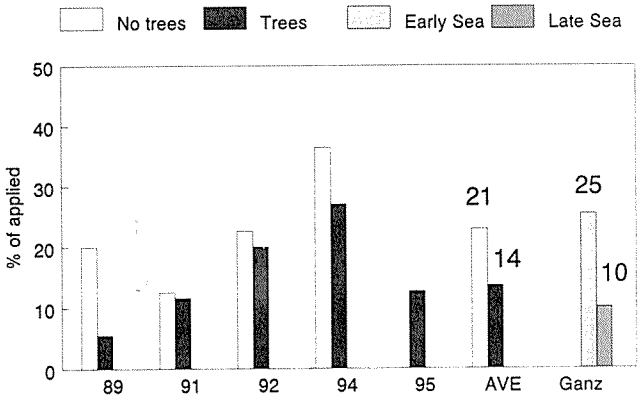

Figure 1. Total ground deposits from the orchard edge to 30 m.

at 30 m downwind were also totaled from the ground surface to 10 m; because data were limited, and several assumptions were made, these results are considered to be subject to large errors, but airborne spray from 0 to 10 m was about 12% of sprayed. Therefore the total of deposits on foliage, on the ground and airborne is 70%. Thus it appears that about 30% or applied spray is still unaccounted for. With no justification, this missing spray is likely to be distributed as 15% additional on foliage, 5% additional to ground deposits and 10% to airborne spray. Thus the spray partition is likely to be about 55% on the foliage, 20% on the ground and 25% airborne as small droplets.

Pergher and Gubiani (1995) measured the effect of spray application rate and vineyard foliage density on spray distribution. Increasing spray application rate and air jet volume produced greater ground deposits and less foliage deposits. Ground deposits were of about 35% of applied spray for 310/390 L/ha application rate and 41 to 49% for 650/730 L/ha application rate. Off-target drift ranged from 6.5 to 10.5% for low air output (7 m^3/s) and from 7.8 to 19.8% for high air volume (8.5 m^3/s). Greatest deposition on foliage (about 55% of amount sprayed) was for low spray volume and low jet air flow rate. Many studies have measured spray deposit patterns from air-blast sprayers in orchard canopies. These studies include: Hall et al. (1975), Whitney and Salyani (1991), Salyani and Whitney (1991), Salyani (1994), Derksen and Gray (1995), Hoffman and Salyani (1996), and Travis et al. (1997) and many others.

Aerial spraying

In most cases, experiments have shown that spraying with either fixed-wing or rotary-winged aircraft produces more drift than other application methods. This is caused by the high travel speed (180-260 km/h for fixed wing), the wing-tip vortices that tend to transport droplets above the wing, and the release height. To reduce drift, spray droplets for many agricultural aerial applications tend to be large, i.e., about 500 μm. In some forestry spraying, very small droplets are used and the wind is used to help increase the effective swath width. The SDTF and the USEPA have adapted a U.S. Forest Service model for use in predicting downwind drift deposits from a variety of aircraft types and spraying conditions.

DRIFT CONTROL METHODS

Education

Several methods can be used to reduce off-site drift. The key to any drift mitigation is the sprayer operator. The operator must configure the sprayer correctly for the crop and must be aware of sensitive sites near the vineyard, nursery, or orchard; must be aware of wind and weather conditions and how they change; and must operate the sprayer in accordance with good drift management principles. In short, sprayer operators must be properly trained and motivated or almost any sprayer system is likely to produce excessive drift.

Calibration

The operator must know how to calculate the amount of chemicals to mix and how to determine tractor travel speed so that he knows how much spray material is being applied.

Drop size control

Drop size is a critical factor in reducing drift. The largest droplet size that will produce the desired biological effect should be chosen to minimize drift. This usually means operating the sprayer at a low system pressure that increases droplet size and/or selecting larger orifice nozzles, or nozzles that produce larger droplet sizes.

Some spray adjuvants are being sold that increase the volume median diameter of spray produced by many nozzles. These 'drift retardants' are normally some type of long chain polymer or gum that increases the viscosity of the spray mixture. Normal application rate for these materials is about 0.0625%. Some studies have found that some of these polymers tend to be sheared by passing through a sprayer pump, as would occur in normal bypass, hydraulic mixing in common agricultural sprayers (Zhu et al., 1997). This means that the drift retardant would lose its ability to increase droplet size – its ability to reduce drift – as the spray tank became empty. Gums are not sheared as easily as the long chain polymers, and some types of polymers (poly-ethylene oxide) are sheared in fewer passes through a pump than other types of polymers (polyacrylamides). In most cases, it is more effective to select nozzles to produce the desired drop size rather than attempt to increase droplet size with an adjuvant.

Nozzles

Dual orifice nozzles reduce the pressure on the flow control orifice; this greatly increases the volume median diameter ($D_{V0.5}$) of spray droplets. However most of these nozzles still produce large numbers of small (less than 150 μm), drift-prone droplets. Air induction (AI) nozzles have been introduced in the last few years. These nozzles provide an air inlet port in a mixing chamber between two orifices. Thus, air becomes entrained into the spray mixture, and most of the small droplets are eliminated. Many studies are now being conducted to evaluate the effectiveness of these nozzles, both to reduce drift and to provide good biological control.

Boom Height

Drift is reduced when droplets are released as close to the target as possible. However the boom must be high enough to provide a good spray pattern from the nozzles. Thus, 80° nozzles must be about 0.5 m above spray targets, while 110° nozzles can be somewhat lower. Boom height is also limited by the possibility of physical damage due to impacting the ground while traveling over rough ground. This danger is increased when travel speeds are increased, when the ground is uneven, and when a boom suspension system is poorly designed. In the U.S. commercial operators with large 'floater' spray rigs often travel 20 to 30 km/h, and so they use large orifice nozzles on booms nearly 2 m above the ground. Any small droplets produced by these nozzles are not likely to reach the ground until carried there by the wind.

Air-assisted

Several commercial sprayers equipped with air jets along the spray booms are now being sold. Hydraulic nozzles direct the spray droplets into the air jets. These air jets should offer some protection against drift, and should improve the penetration

of spray into target canopies. However the angle and air velocity of the jet must be adjusted to provide optimum results. Factors that must be considered in the jet operation include the wind velocity and direction, travel speed and direction with respect to the wind direction, and ground cover (plant canopy) being sprayed.

Electrostatic

Some commercial sprayers now feature electrostatic charging of spray droplets. These sprayers are more expensive to purchase, however may be valuable for treating some high value crops. Some studies have shown improved deposition with electrostatic spray, however other studies have not found significant improvement. To obtain a strong electrostatic force between spray droplets and plant surfaces, the charge-to-mass ratio must be large. However to achieve a large charge-to-mass ratio, droplets must be small, which also makes them more susceptible to drift. The electrostatic force is not effective until droplets move close to leaf surfaces, so if a wind is present, small droplets may be carried away from target plants before droplets are close enough for electrostatic forces to become effective.

Shields

Mechanical shields have been adapted to commercial sprayers for several years (Rogers and Ford, 1985) . These units allow farmers to spray when wind speeds would be too great to permit spraying with conventional boom sprayers. However totally enclosed 'shrouded' sprayers have the disadvantage that the operator can not see if the spray nozzles operating properly, i.e., if a nozzle is plugged. Most studies have shown that these shields do reduce drift by about 90% (Wolf et al., 1993). Other shields made of mesh fabric have also been sold. In wind tunnel studies, Ozkan et al. (1997) have shown that mesh shields are less effective than more conventional solid shields.

Wind

In the U.S., some states have regulations that prohibit spray application when wind speed are above a fixed velocity, such as 20 km/h. Sprayer operators must know where sensitive areas are located with respect to the sprayed field, and must monitor wind speed and direction during spray application. The operator must be responsible for halting spray application if wind speed or direction creates a threat of drift to a sensitive area.

Inversions

Atmospheric stability affects the vertical mixing of the spray cloud into the air and can affect the distance spray droplets drift. Often very stable conditions (vertical mixing suppressed) is associated with low wind velocities, so it is difficult to separate the effect of wind speed from stability. Most research studies have measured increased ground deposit at downwind distances less than 10 m when stability increased. With calm winds and very stable conditions, many experts advice against spraying. Under these conditions, small droplets can "hang" in the air and then be carried by slow moving air currents several 100 m and the entire cloud deposited in high concentrations. This cloud may move in any direction so any

sensitive area close to the sprayed field may be affected. Watt (1979) gives some anecdotal stories of aircraft spraying under these conditions.

Biological agents – less toxic pesticides

While the pesticide used does not necessarily affect the amount of drift, in some cases growers have changed pesticides when spraying portions of crops where the danger of contaminating a sensitive area was great. In these cases, a less toxic, or biological control agent would be used, so even if drift occurred, the danger to the sensitive area (such as a school, swimming pool, or playground) would be low.

DRIFT MITIGATION TECHNIQUES – GROUND BOOM SPRAYERS

1. Use nozzles that produce large droplets whenever possible, if biological effectiveness can be maintained.
2. Keep the boom close to the spray target.
3. Use nozzles with narrow spray-fan angles.
4. Use greater spray volume and use nozzles with larger orifices.
5. Use lower system pressure and check pressure gauge accuracy.
6. Use drift retardants if droplet size can not be controlled with nozzle selection.
7. Follow label recommendations to avoid drift with highly volatile pesticides.
8. Avoid spraying on extremely hot, dry days, especially if sensitive vegetation is nearby.
9. Do not spray when conditions are favorable for an atmospheric inversion.
10. Do not spray when wind speeds are greater than 15 km/h.
11. Avoid spraying near sensitive areas located downwind. Leave a buffer strip 20 to 30 m wide and spray this strip later when the wind shifts.
12. Be sure to keep good records and evaluate spray results.
13. New label requirements may use a drift model to determine the required buffer width. Travel slower (and lower boom height) and use nozzles which produce large droplets near sensitive areas. This will reduce the required buffer zone width, then, as distance from the sensitive area increases, nozzles can be changed to produce smaller droplets, if desired, and boom height raised so travel speed can be increased.
14. Select the time when drift is likely to be low for spraying the parts of the field near sensitive areas.
15. In the future, label requirements may specify nozzles that produce a certain droplet size spectrum, such as fine, medium, coarse, very coarse, etc.

DRIFT MITIGATION TECHNIQUES – ORCHARD AND VINEYARD SPRAYERS

Many of the same principles for reducing drift for boom sprayers apply to orchard spraying as well. With airblast sprayers, we have to remember that the

droplet release height is where the air jet no longer controls the droplet trajectory and the wind begins to direct droplet paths. In some cases, this may be several meters above the tree canopy. Some of the practices for reducing drift are: 1) keep the spray as close to the ground as possible; 2) minimize the small droplet fraction; 3) match the sprayer air jet and nozzle system to the trees being sprayed; 4) use special techniques near sensitive areas. Most of the techniques discussed below use one or more of the techniques mentioned above.

Overhead application

Carpenter et al. (1985) tested a micro-irrigation system over the tree row as a possible automatically controlled pesticide application system. They were able to design a system that worked fairly well, but the system required a large amount of water and wind currents prevented uniform coverage under some conditions.

Tree sensing

McConnell et al. (1983) proposed a spray system that would use ultrasonic sensors to evaluate tree volume for use in control of spray volume. Sutton and Unrath (1984) discussed using tree volume as a basis for the volume of spray to be applied. Giles et al. (1987) used a tree sensing system and a spray control system to develop an air-blast orchard sprayer that sprayed only when canopy was detected. The sprayer used sensors at three elevations to detect foliage; each sensor controlled spray from the nozzles directed at the associated elevation in the tree. They tested the sprayer in a peach and an apple orchard. They found that tree-sensing/spray control saved 28 to 35% of spray material in the peach orchard and 36 to 52% of spray in the apple orchard, compared to the same sprayer without controlled spraying. Spray cards were used to evaluate spray deposit at locations within the trees. Targets at some locations, near the leading edge of foliage near tree gaps and in the upper regions of the tree, received less spray when the tree-sensing system was used. Commercial units that use this type of system have been available for several years. In Spain, Rosell et al. (1996) developed an electronic selective spraying system which sensed tree volume as the sprayer moved down the row and adjusted sprayed volume to match measured tree volume. If no tree canopy was detected, then no spray was applied. Spray trials in pear trees found that about 50% less spray was applied with the selective sprayer as compared to the same sprayer with the sensing controller system not used.

Tunnel sprayers

Home built tunnel (over-the-row) sprayers have been used in crops such as grapes and small fruit for some time. With increased concern for drift reduction, several researchers throughout the world have recently designed and tested experimental tunnel sprayers. It is likely that this technology will be adopted for tree fruit in Europe more quickly than in the U.S. because recent plantings of apple orchards in Europe tend to be more uniform, dwarf varieties. Tunnel sprayers may not only reduce drift and improve deposit, but allow the possibility of collecting spray that misses foliage for reuse. A disadvantage of the tunnel sprayer is the size of trees that can be treated and problems associated with driving such a large machine through the orchard. Morgan (1983) reported that experimental over-the-

row devices had been used in spray trials on fruit crops in Great Britain several years earlier. Tennes et al. (1976) developed an over-the-row harvester that could straddle trees 2.6 m wide and 3.7 m high. Reichard et al. (1982) developed an inline injection sprayer attachment for this unit. Schmidt (1990) measured ground and airborne spray while using a tunnel sprayer that collected and recycled spray that collected on the tunnel walls. The tunnel sprayer with recycling produced about half the ground deposits as a standard axial fan sprayer.

Van de Werken (1991) described the development of a fully automatic air-assisted tunnel sprayer for use in apple orchards. This self-propelled unit also recycled s99pray deposited on the tunnel walls. This sprayer required a travel path at least 0.4 m wide for travel. It could spray tree-rows up to 2 m wide and 3 m high at travel speeds up to 6.3 km/h. They found that 90% or more of the spray was deposited on trees with this sprayer. Cross and Berrie (1993) compared spray deposits and efficacy of sprays applied to apple trees with a tunnel sprayer and a conventional sprayer. More deposits and better scab control was achieved with the tunnel sprayer applying 100 and 200 L/ha compared to conventional or tunnel sprayers applying 50 L/ha. Peterson and Hogmire (1994) developed and tested a self-propelled sprayer for dwarf fruit trees. The tunnel was 2.4 X 4.7 m, with a vertical clearance of 2.4 m. Three air-delivery systems were used within the tunnel unit: 1) no air; 2) four Proptec® fans; 3) four cross-flow fans. They measured deposit within the tree canopy and drift from these sprayers and from a conventional axial-flow fan sprayer while applying 190 L/ha. Samples were taken from the outer 0.5 m and in the center of the tree canopy, between 0.7 and 1.7 m elevation. The cross-flow fan units deposited more spray in all sections of the trees than the Proptec equipped sprayers. Hydraulic nozzles without fans had good deposits in the upper parts of the trees. Hydraulic and spinning disk nozzles produced similar deposits in all sections of the tree. In a single test, low volume (187 L/ha) produced greater deposits than high volume (935 L/ha). The best tunnel configuration produced greater deposits than the conventional sprayer. The tunnel sprayer had significantly less drift than the conventional sprayer.

Holownicki et al. (1996) compared two tunnel sprayers, one with cross-flow fans and the other with eight directed air-jets with a standard sprayer with 10 directed air-jets. Tree-row size was 2 m wide and 2.5 m high, with a row spacing of 4 m. There was no significant effect of travel speed and spray volume on total deposits. Increased travel speed caused slightly reduced spray deposits for the tunnel cross-flow sprayer. For targets along the vertical centerline-axis of the tree, significantly greater deposits were measured for the standard compared to the tunnel cross-flow sprayer. They measured the ratio of outside to inside canopy deposit. Measured ratios were: directed air-jet tunnel sprayer - 1.5 to 3, cross-flow tunnel sprayer - 7.5 to 14.6, and directed air jet sprayer - 5 to 12.7. Thus the best distribution was for the directed air jet tunnel sprayer. Wilson, et al. (1995) developed an over-the-row dust applicator for fruit trees. The tunnel was 4.3 m in all three directions. Measured deposits varied from 15 to 36 mg/cm^2 on sampled leaves taken from three trees at 0.2 m in from the canopy edge, at 1 and 3 m elevations and at 4 quadrants within the tree.

When spraying dormant trees, Siegfried and Holliger (1996) reported that in small trees, a tunnel sprayer achieved 60% greater deposit on branches, twigs, and scaffold compared to an axial-fan sprayer; however, deposit was not improved in

older fruit trees with wide tree tops. Ground deposits were 20-40% lower and drift was reduced by 70% with tunnel spraying compared to axial-fan spraying. At full foliage, the tunnel sprayer deposited about 20% more sprayed material on leaves than axial-fan sprayers. However, at full foliage, ground deposit with the axial-fan sprayer was reduced to within 5% of the tunnel sprayer (28% to 23%).

Reports of several other studies on tunnel sprayers are contained in the Symposium proceedings cited earlier (A.N.P.P.-B.C.P.C., 1993).

Barriers

Orchard trees have been shown to be good collectors of spray that penetrates target trees. Riley and Wiesner (1990) reported that most ground deposit resulted from spraying the last, downwind row. Downwind ground deposits decreased rapidly as the sprayed row was farther from the downwind edge of the orchard. They developed a regression equation to estimate deposit produced from spraying interior rows, based on row distance from the orchard edge. The SDTF (1998) measured large decreases in deposit away from the sprayed row in the interior of an orchard. Thus a major factor in downwind deposit near the orchard is the spraying of the last few rows. Special treatment of these rows can greatly reduce off-target drift.

Researchers in New Zealand have conducted several studies on the effect of shelter belts on drift from orchard sprayers. Graham (1987) measured ground and airborne spray deposits downwind from a conventional orchard sprayer as it sprayed in the open (no shelter belt), through a natural (live) shelter, and through an artificial shelter. The natural shelter included *Casurina spp* and *Matsudana spp* which were about 7.6 to 10 m high. The artificial shelter was made of medium porosity Sarlon cloth, 6 m high. Measured ground deposits of the fungicide Ronilan, used as the tracer, are shown in Figure 2. Ground deposits appear to be reduced by the presence of shelters; the live shelter had a greater effect than the artificial shelter. They used both air samplers and rotating slides to collect airborne spray. Air samplers collected more spray then either ground or rotation slides on an area basis. The live shelter also produced the greatest reduction in airborne spray collected by both methods, but the artificial shelter also reduced deposits compared to no shelter. They suggested that the "ideal" porosity for a live shelter was such

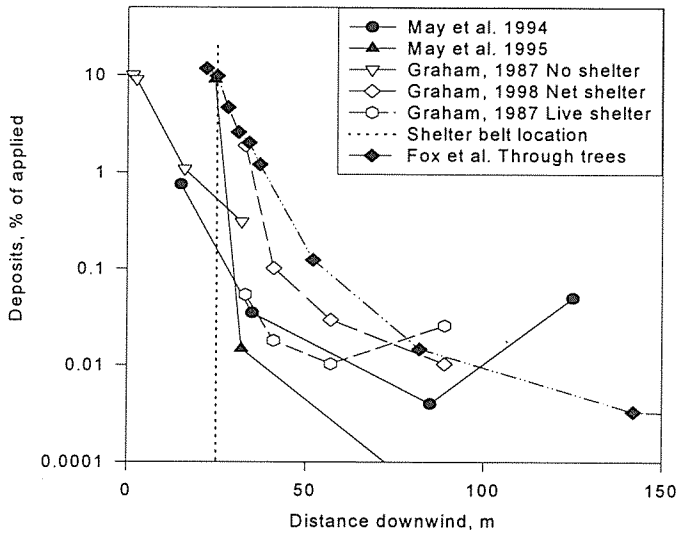

Figure 2. Ground deposits downwind from shelter-belts.

that you could see the sprayer through the trees, but could not see any detail, such as make, driver, etc. Artificial shelters made of woven cloth should have an optical porosity of 40 to 50%.

May et al. (1994) used a conventional orchard sprayer for three trial sprays along a path in a grass field, 25 m upwind of a live shelter which contained poplar trees, 9 m tall and 2.7 to 5.8 m wide. They measured ground and airborne spray deposits at 10 m before and 10, 60, and 100 m beyond the shelter belt. The shelter was trimmed after the second trial so a 2 m tall fence of shade cloth was installed to reduce spray passage. Thus trial 3 had much less deposit that the first two, even though the wind was greater during trial 3. The wind during the first two trials was less than 10 km/h. They concluded that, for the conditions of their study, the shelter belt was not effective in reducing downwind deposits. Mean ground deposits for their trials are plotted in Figure 2. Ground deposits at 128 m were noticeably greater than deposits at 85 m, for all trials. It was not determined if this was a result of air flow patterns over the shelter-belt or not. Graham (1987) also measured an increase in deposits on the last downwind ground sampler (see Figure 2).

In another study, May (1995) measured deposits beyond a large, dense evergreen shelter-belt when a persimmon orchard was sprayed. They used two pesticides as tracers. Ground deposits were below detectable levels at 75 m downwind. However, detectable levels of airborne spray were measured at 75 m downwind. These results are also plotted in Figure 2. Combined ground deposits measured by Fox et al. (1990,1992,1994) downwind from spraying through a single row of semi-dwarf apple trees are shown in Figure 2 for comparison.

Summary of drift mitigation practices for airblast sprayers

Drift mitigation methods can be summarized then as:

1. if there's nothing there, don't spray it;
2. keep the spray as close to the ground as possible;
3. minimize the small droplet fraction; however remember that the purpose of spraying is to control pests. Large droplets may not provide the control desired, without increasing the application rate;
4. match the sprayer air jet (volume and direction) and nozzle system to the trees being sprayed;
5. Be prepared to use special techniques near sensitive areas, especially for the last few downwind rows. These may include: a) use large droplets; b) use techniques to direct spray at targets better, such as a handgun; c) spray the last few rows upwind only; d) wait and spray when the wind shifts; e) use special measures or equipment to create barriers or direct spray at the target (tunnel sprayer, etc.).

In their discussion of reducing pesticide drift, Hall and Fox (1996) report a summary of recommended procedures for reducing off-target movement of pesticides. This list of actions, resulting from a Tree Crops Workshop held in 1993, and provides a good summary of approaches that should reduce drift from orchard spraying. An abstract of this action list is given in Table 3.

Table 3. Mitigation options for Orchard Air-blast Applications*

Action	Rank	Estimated % drift reduction	Comments
Education	1-3	20%	1. Survey current practices 2. Train individuals to critically adjust sprayer for planting geometry match/season and tree size
Modify edge practices	1-3	40-50%	1. Least costly and probably easiest practice to accomplish 2. Spray inwards on outer 4-6 rows 3. Decrease spray volume (psi and/or liquid volume) 4. Automatic or manual shut-off (sprayer) on last 4-6 rows.
Restriction of ai/applications	4	15-20%	1. Restrict by ai and time of day [not 10:00 am to 4:00 pm] 2. Can restrict ai, e.g., safe pesticides only in high risk areas
Sensors	5	20-25%	1. This technology should be accelerated; currently not cost-effective for small growers.
Buffer zones	6	15-20%	1. Effectiveness would depend upon width of buffer, size of tree and/or block, and sprayer
Tower and/or tunnel sprayers	7	10-80%	1. No documentation of % reduction, although visual evidence suggests an increased target placement efficiency; hence a reduced off-target movement. 2. Tunnels useful only for 2.4 m trees/vines [e.g. less than 5% of apple acreage in the USA and no other tree crops]
Narrow droplet spectrum	8	10-15%	1. Possible with "dialable sprayers". Need to change nozzles "on the go".
Wind breaks	9	20-40%	1. Not for pecans or other high trees. 2. Practicality of strategy; will it create other problem?
Overhead or chemigation	10	20%+	1. Use of large drops would reduce off-target movement 2. Limited to certain sites/crops, but has irrigation potential as well.

* Adapted from Hall and Fox (1996)

Drift mitigation for aerial application

There are only a few options available for reducing drift when spraying with aircraft. The first step is an operator who is carefully trained so he/she can make good decisions on when to spray and when to stop spraying. The operator must use a spray offset carefully. That is, he must calculate how far the wind will carry the main spray swath and plan his spray paths to allow for this spray adjustment. The use of global positioning instruments in aircraft should assist the pilots in making sure they are spraying the correct field and in selecting the proper spray paths. New computer software may soon be available to select optimum spray paths in real time, based in local wind and spray conditions. The largest droplet size that will produce the desired biological effect should be chosen.

SUMMARY

Spray drift can be minimized by proper sprayer operation. The key to any drift mitigation is the sprayer operator. The operator must configure the sprayer correctly for the crop and must be aware of sensitive sites near the spray site; must be aware of wind and weather conditions and how they change; and must operate the sprayer in accordance with good drift management principles. Spray practices that reduce drift include: spray large droplets, or use nozzles that produce fewer small droplets, but make sure the desired biological effect is attained; adjust boom height as low as possible, while maintaining a uniform spray pattern across the swath; apply special practices near any sensitive area; use shields to reduce wind effects; spray only when the wind velocity is less than 15 km/h; and wind direction does not threaten sensitive areas such as houses, schools, streams, or other crops that may be damaged or contaminated by the spray material being applied.

Several different methods can be used to reduce off-site drift for airblast sprayers in orchards or vineyards. Some rules of good sprayer operation are: if there's nothing there, don't spray it; spray the last few downwind rows only into the wind; use the largest droplets that will produce the desired biological efficacy; match the sprayer jet and nozzle flow rate to the trees in the orchard.

Other ways to decrease drift include: use tunnel sprayers; use windbreaks downwind of the sprayed area; provide buffer zones between the sprayed area and sensitive neighbors; and use special spraying techniques for parts of the vineyard or orchard where sensitive areas may be subject to drift. These may include spraying some areas only when wind direction is suitable or using biological control or low toxicity pesticides in some areas of the application site.

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